DEEP SPACE TELECOMMUNICATIONS

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The increasing load on NASA's deep Space Network, the new capabilities for deep space missions inherent in a next-generation radio telescope, and the potential of new telescope technology for reducing construction and operation costs suggest a natural marriage between radio astronomy and deep space telecommunications in developing advanced radio telescope concepts.

1 Introduction

The constraints imposed on the design of deep space telecommunications link leads to technical requirements which are very similar to those for radio astronomy – large collecting areas, low noise receivers, operational flexibility.

1.1 Deep Space Telecommunications Link Budget

The communications link between a ground station and a spacecraft is governed by a symmetrical pair of equations for the uplink and dowmlink sdata rate in bits per second:

$$R_{up} = KP_{gnd}A_{gnd}\frac{A_{sc}}{D^2 T_{R_{sc}} \lambda^2} \tag{1}$$

$$R_{dn} = KP_{sc}A_{sc}\frac{A_{gnd}}{D^2 T_{R_{gnd}} \lambda^2} \tag{2}$$

where K is a constant involving physical and geometrical constants, various losses and the coding efficiency, P is the transmitter power, A is the antenna collecting area, and T_R is the receiver system temperature, with the suffixes gnd and sc referring to the ground station and the spacecraft respectively. λ is the wavelength. The ratio of these two equations shows that deep space telecommunications are limited by the downlink rate:

$$\frac{R_{dn}}{R_{up}} = \frac{P_{sc}T_{sc}}{P_{gnd}T_{gnd}} \tag{3}$$

Putting in some typical numbers we find

$$\frac{R_{dn}}{R_{up}} = \frac{20\ W \times 300\ K}{20\ kW \times 20\ K} = 0.015$$

The advantage in transmitter power on the ground handily overcomes the disadvantage of the receiver system noise on the spacecraft.

There isn't much that can be done on the spacecraft to improve the downlink rate:

Transmitter efficiency can be improved somewhat, but it is mainly limited by power available on the spacecraft.

Deployable antennas make mission designers nervous (especially since the Galileo mission. There is active technology development in this area, technology for very large deployable antennas is still some time in the future.

Wavelength can be reduced but the technology becomes more difficult. The transition from 8 GHz to 32 GHz (see below) is now being made, slowly because missions prefer proven technology. Optical communications are under active development. Some preliminary research is being done around 90 GHz.

Increasing the spacecraft antenna aperture or reducing the wavelength, or using optical communications, requires accurate and expensive pointing systems. On the ground, receiver system temperature is hitting limits imposed by the atmosphere, antenna design, and the CBR. The only thing that can be improved significantly is collecting area on the ground.

1.2 Deep Space to Earth Band Allocations

Any collaborative technology development must recognize the frequency bands for the deep space telecommunications downlinks shown in Table 1. By the time that the SKA becomes a reality, S-band will probably have disappeared as a primary downlink frequency. Most missions should be using Ka-band in seven or eight years, but there is still reluctance to be the first to use new technology. Proposals will be presented at the World Radiocommunication Conference in 2000 by the US, Europe, and other countries to move the allocations for the noisiest near-Earth and geostationary satellite transmitters out of this band. However, mm-λ communications are not currently being considered by the Deep Space network.

Table 1: Spectrum Allocations for Deep Space Downlinks

Band		MHz	Notes
			Primary Allocations
2.29	2.30	10	S-band, becoming obsolete[1]
8.40	8.45	50	X-band, deep space only
8.45	8.50	50	X-band, includes near-Earth
31.80	32.30	500	Ka-band, deep space only, future missions[2]
37.00	38.00	1000	Ka-band, includes near Earth
			Secondary Allocation
74.00	84.00	10,000	primary for various satellite services[3]

Optical communications are not expected to suffer from interference due to other spectrum users in the same way that radio communications are. However, the growth of light pollution [2,3] must certainly be taken into account.

2 Improving Link and Network Capacity

The design of a mission must take into account two types of capacity:

Network Capacity: The ability to provide tracking time to an increasing number of missions.

Single Link Capacity: The ability to concentrate resources on a single mission for critical events.

Both are measured by the metric

$$\frac{G}{T} = \frac{4\pi A_{eff}}{\lambda^2 T_{sys}} \tag{4}$$

which includes the three key Earth-based parameters in the downlink: effective collecting area, system temperature, and wavelength. G/T is usually expressed in dB[K^-1] but for the purposes of graphical comparison this paper will use K^-1.

Missions which must downlink over a very large distance or have a large data rate (or both) for critical events must design around the single link capacity. For very exceptional events, the entire capacity of a communications complex will limit the capacity. Network managers who must schedule support for an ever increasing number of missions must work within the constraints of the total network capacity.

3 Mission Needs

Fig. 1 shows that the number of mission under various scenarios, from a bleak "no new missions" to Dan Goldin's vision of many small missions, with a launch approximately every other month. Even with a conservative scenario based on the missions now planned, the

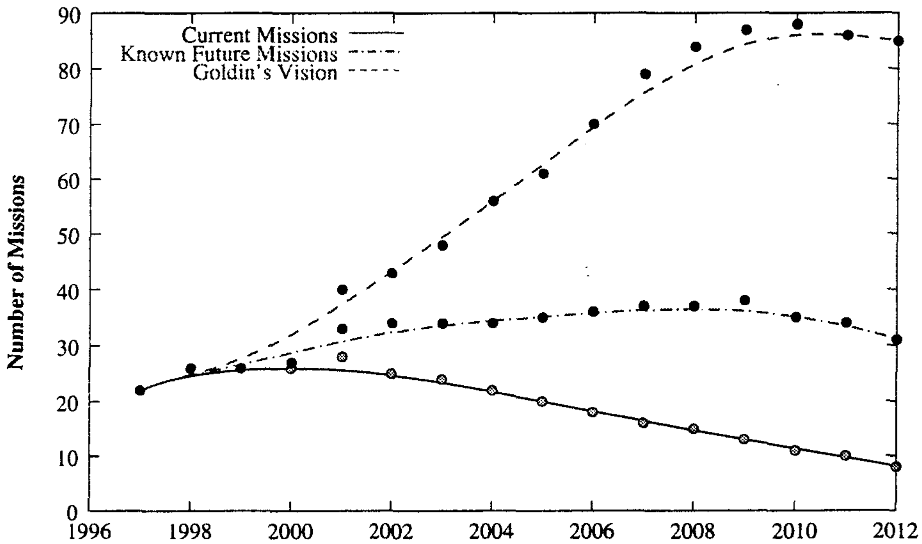

Figure 1: The number of missions that will be flown, that are expected to be flown, and that could possible be flown in roughly the next decade.

number of missions will increase by about 30% over the mid-1999 number. Fig. 2 shows the need for tracking hours will increase by about 70data returns. Not reflected in these graphs is a general desire on the part of the missions to have higher downlink data rates, which are constrained by network G/T.

4 DSN Upgrade Plans and Options

The DSN currently plans, subject to funding future levels, to upgrade the network in various stages [1]. The first stage is to add a Ka-band capability to some as yet uncertain number of beam-waveguide (BWG) 34-m antennas. Fig. 3 shows the improvement in the DSN's total G/T that will result from one antenna upgrade (open circle) and all five antennas. The improvement and cost factors are relative to the cost of a new 34-m BWG with dual X/Ka

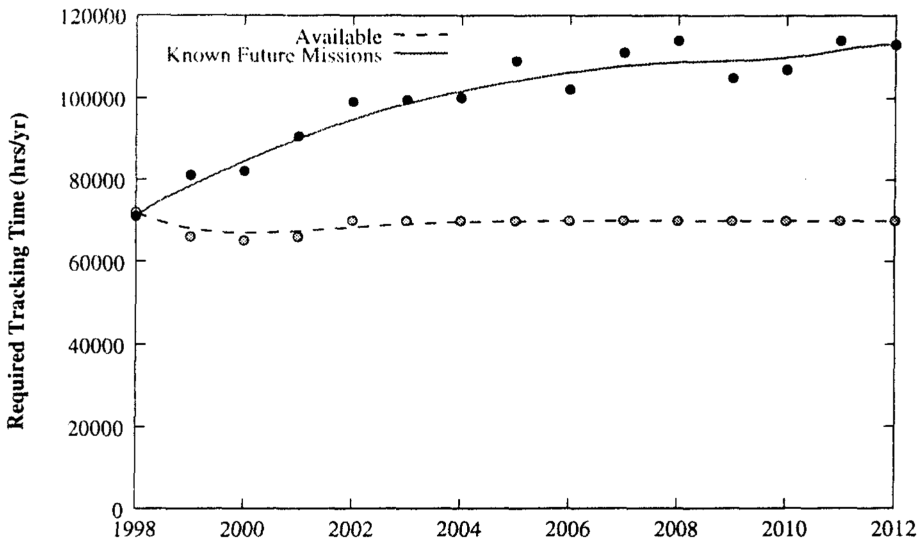

Figure 2: The capacity of the Deep Space Network, with no improvements, is compared to the capactiy required by the missions now planned.

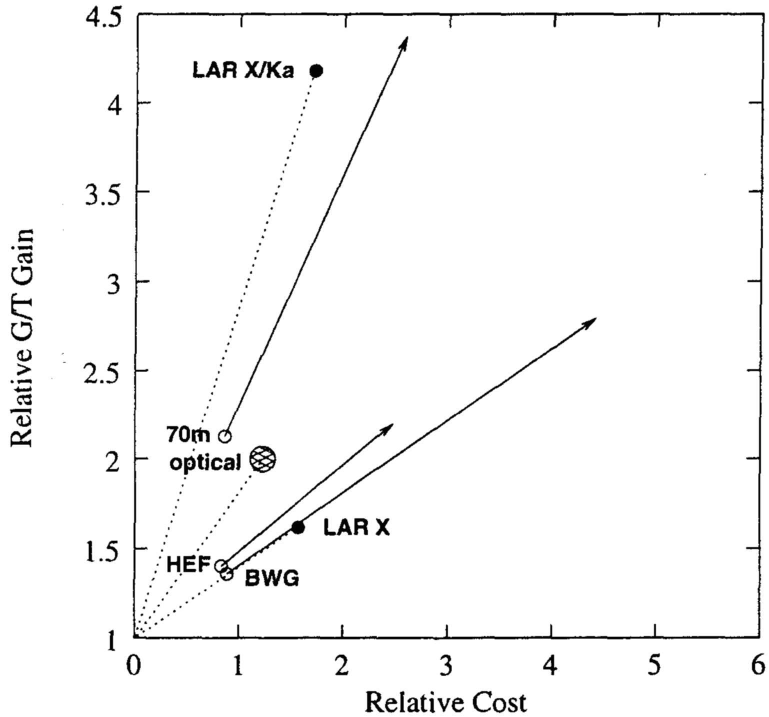

Figure 3: The open circles and arrows represent the increase in total network G/T to be achieved by upgrading existing antennas to operate at Ka-band. The circles indicate the upgrade of one antenna of each type and the arrows the upgrade of all antennas. For the optical station and the LAR, the increase for only one station is shown. The slope of the dotted lines and arrows is the benefit/cost ratio.

capability. The next most likely upgrade, because the risk is low, would be adding Ka-band capability to one or more high-efficiency (HEF) 34-m antennas. Technology development is underway to enable upgrades of the 70-m antennas to Ka-band. If successful, this would provide G/T increases at less than half the cost of 34-m upgrades.

To compare the possible network improvement that would result from an SKA station, the performance parameters for the Canadian Large Area Reflector (LAR) were used: a 200 m circular aperture with 60% efficiency pointed to 30° elevation and 20 K system temperature at

X-band. The LAR is not currently envisioned to operate at Ka-band but a 30% efficiency and 35 K system temperature were assumed. In order to remove from consideration the specialized (and expensive) telemetry electronics, the total cost of an X-band LAR was taken to be that of a 34-m BWG plus the cost of a LAR (Dewdney, this proceedings). For Ka-band operation, the cost of the LAR was increased by US$ 5 million. Adding one Ka-band LAR to the DSN provides as much G/T improvement as upgrading all the 70-m antennas, at about three quarters of the cost.

Note that the greater portion of the cost is in the 34-m antenna used to feed the LAR, and it would be a useful network addition in its own right. This mitigates some of the risk associated with LAR technology. The reason for not using an existing BWG antenna is that none are suitably located for adding a LAR.

5 Conclusions

With due attention to NASA's telecommunications requirements, it should be possible to interest the DSN in becoming a partner in the Square Kilometer Array Consortium for the purposes of technology development and testing.

A LAR-like SKA station operating at X-band could be used to increase the network's G/T at the same benefit/cost ratio as upgrading existing 34-m antennas to operate at Ka-band. While this would not offer a cost reduction to the DSN, it would allow the missions to used less expense, well-understood X-band equipment onboard. The challenge to the SKA community would be to demonstrate that the technology is viable.

A LAR-like SKA station operating at Ka-band would increase the DSN's capacity dramatically, at significantly less cost than any other approach now being considered. The difference is big enough that NASA should consider seriously in participating in appropriate SKA technology development.

Acknowledgements

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